Vibroacoustic Analysis of Large Heat Rejection Radiators for Future Spacecraft

Abstract: Spacecraft structures such as antennas, solar arrays and radiator panels significantly respond to high acoustic levels seen at lift-off. Some future spacecraft may utilize nuclear electric propulsion that require large radiator panels to reject waste heat. A vibroacoustic assessment was performed for two different radiator panel designs. Results from the analysis of the two designs using different analytical approaches are presented and discussed.

Vibroacoustic Analysis of Large Heat Rejection Radiators for Future Spacecraft

Presented at the
2005 Spacecraft and Launch Vehicle
Dynamic Environments Workshop

Jeffrey M. Larko
Mark E. McNelis
William O. Hughes

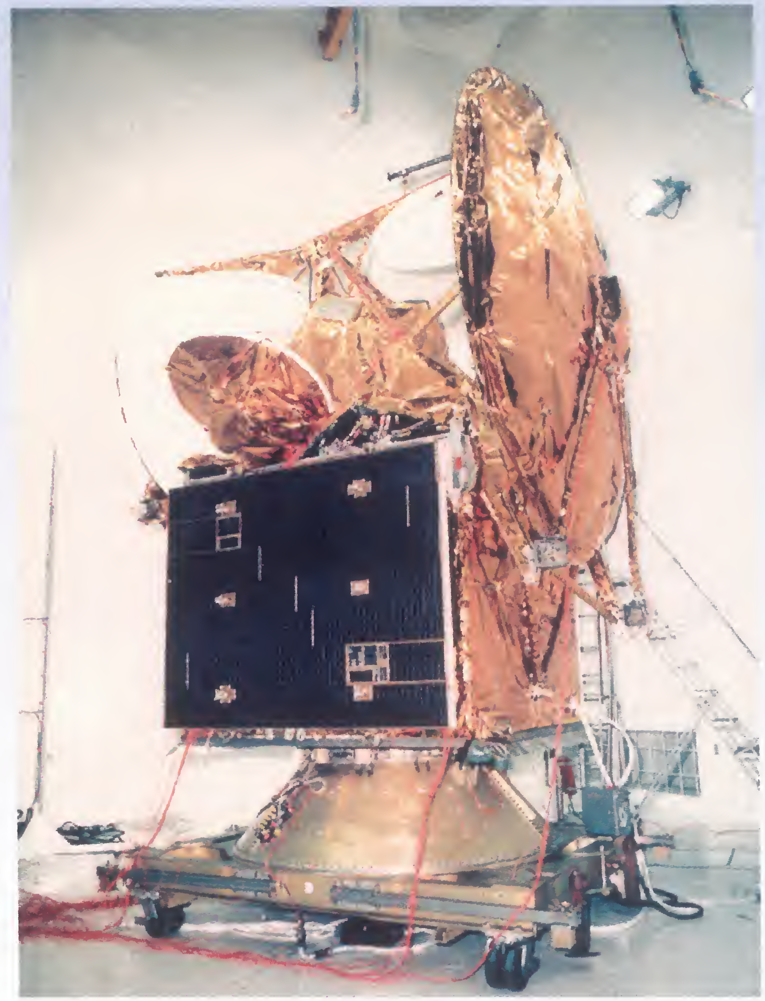
June 21, 2005
The Aerospace Corporation
El Segundo, CA

Introduction

- Future spacecraft (i.e., Jupiter Icy Moon Orbiter-JIMO, other Prometheus class spacecrafts) may utilize nuclear electric propulsion. Large heat radiator panels will be required to reject waste heat from the reactor.
- Some early conceptual designs have shown lightweight heat radiator panel areas up to 450 m^2.
- Based on past experience, it is known that structures such as solar arrays, antenna dishes, and radiator panels significantly respond to the high acoustic levels seen at lift-off.
- Therefore, an early vibroacoustic assessment of two different radiator panel designs was performed to study this critical loading.

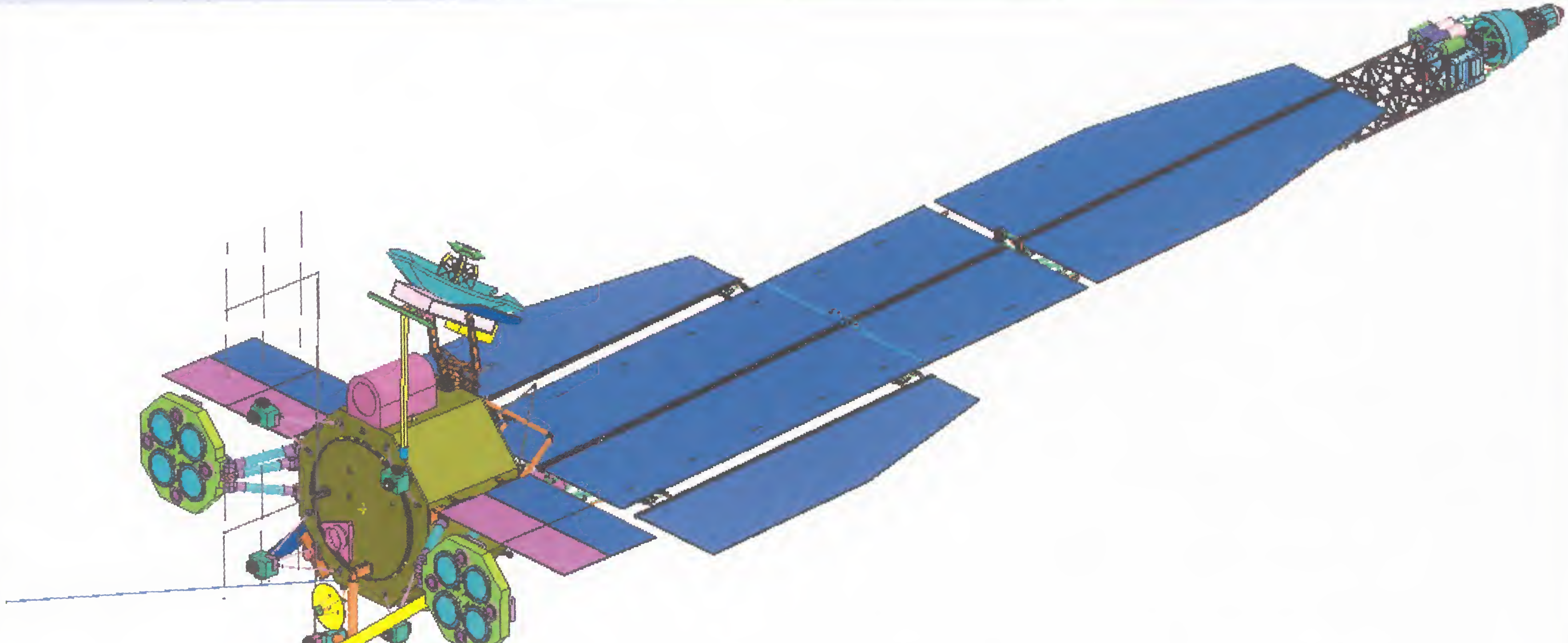
Typical Acoustic Response of Past Spacecrafts

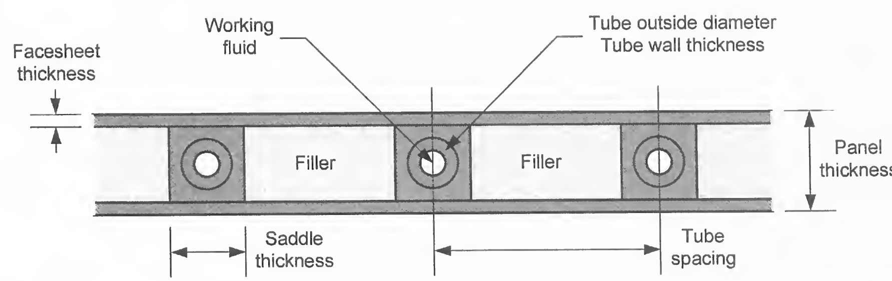
- ACTS (Acoustic Test Data)
  - Solar Array: 25-60 Grms
  - Main Antennas: 50-100 Grms
  - Subreflectors: 35-70 Grms
- Space Station
  - Thermal Radiator:
    - MTAM Acoustic Test: 72 Grms
    - SEA Prediction: 47 Grms
- Spacecraft Solar Panels (Acoustic Test Data and SEA Predictions):
  - Magellan: 18-40 Grms
  - Mars Observer: 14-23 Grms
  - Topex: 10-54 Grms



ACTS Spacecraft

Prometheus Spacecraft Configurations: Sandwich Panel Radiator Design (Deployed)

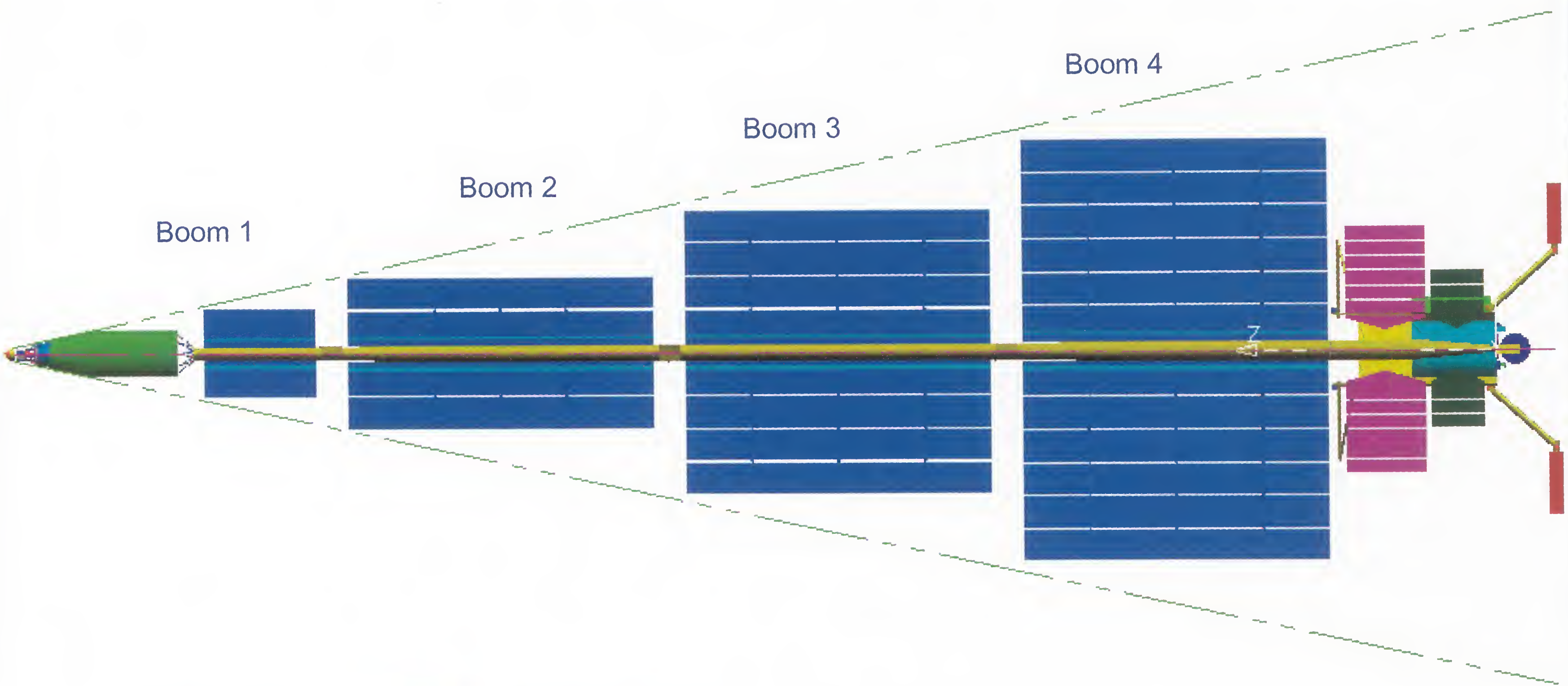




Sandwich Panel Cross Section

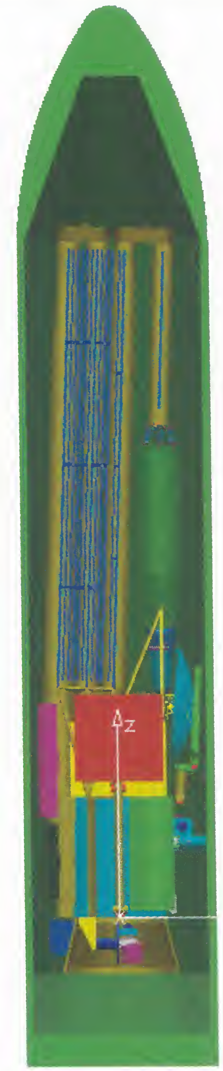
Prometheus Spacecraft Configurations: Sandwich Panel Radiator Design (Stowed)

Prometheus Spacecraft Configurations: Single Fin Radiator Design (Deployed)

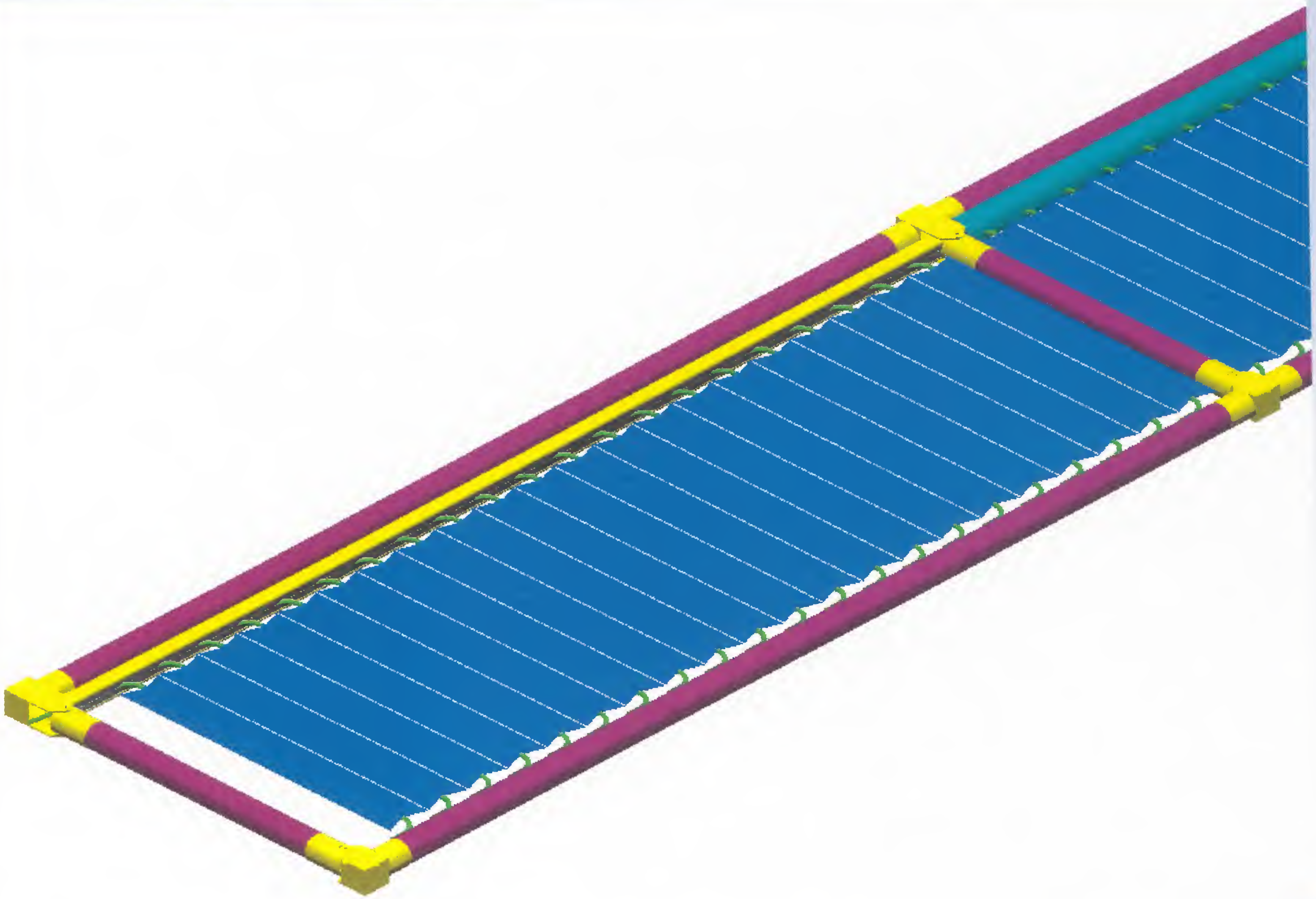


Single Fin Radiator Cross Section

Prometheus Spacecraft Configurations: Single Fin Radiator Design (Stowed)

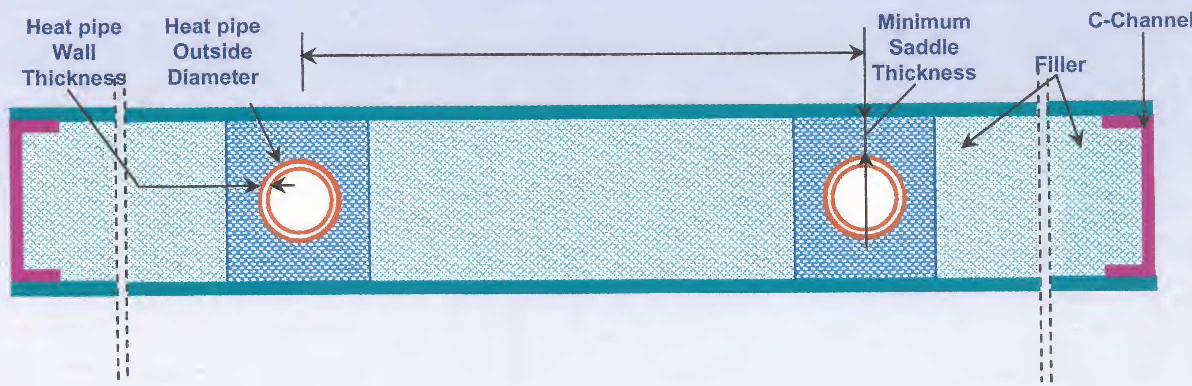


Single Fin Radiator Array Detail

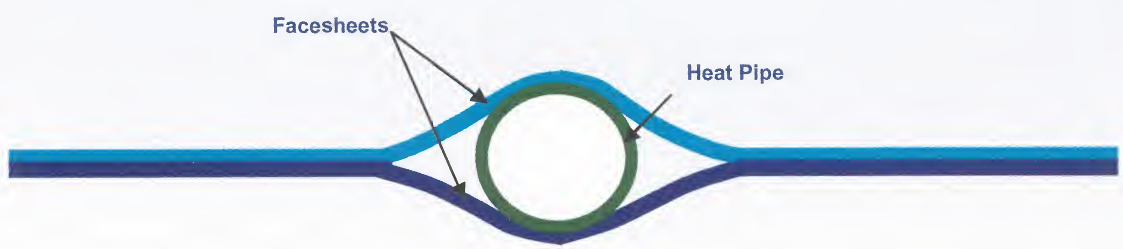


Radiator Panel Cross Sections

Sandwich Panel
Radiator Construction

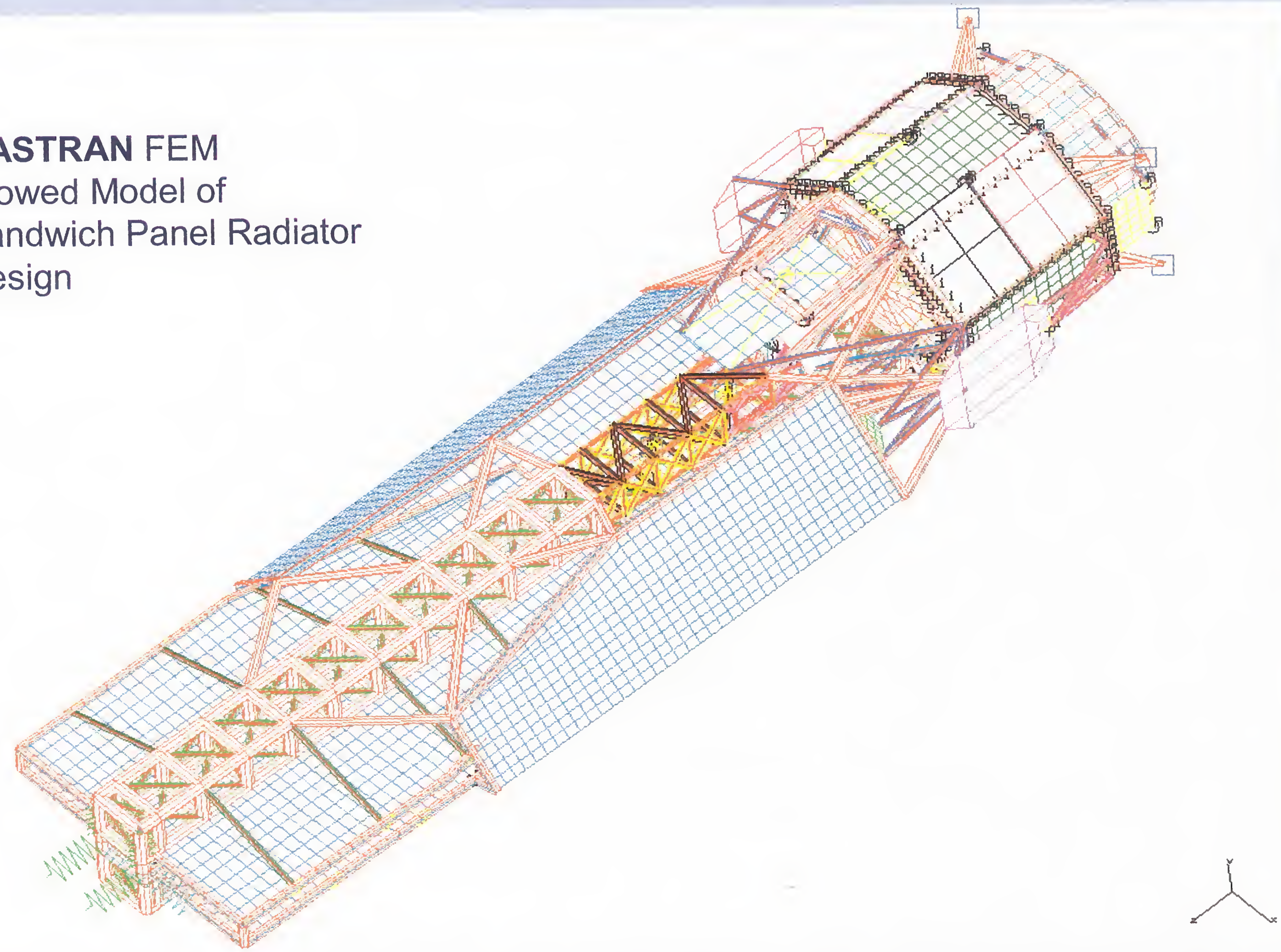


Single Fin
Radiator Construction



Overview of AutoSEA Modeling

NASTRAN FEM
Stowed Model of
Sandwich Panel Radiator
Design



- Sandwich panel radiator configuration imported into AutoSEA from existing NASTRAN Finite Element Model
  - AutoSEA model created using NASTRAN grid geometry
  - Truss support structure not modeled

Overview of AutoSEA Modeling (cont.)

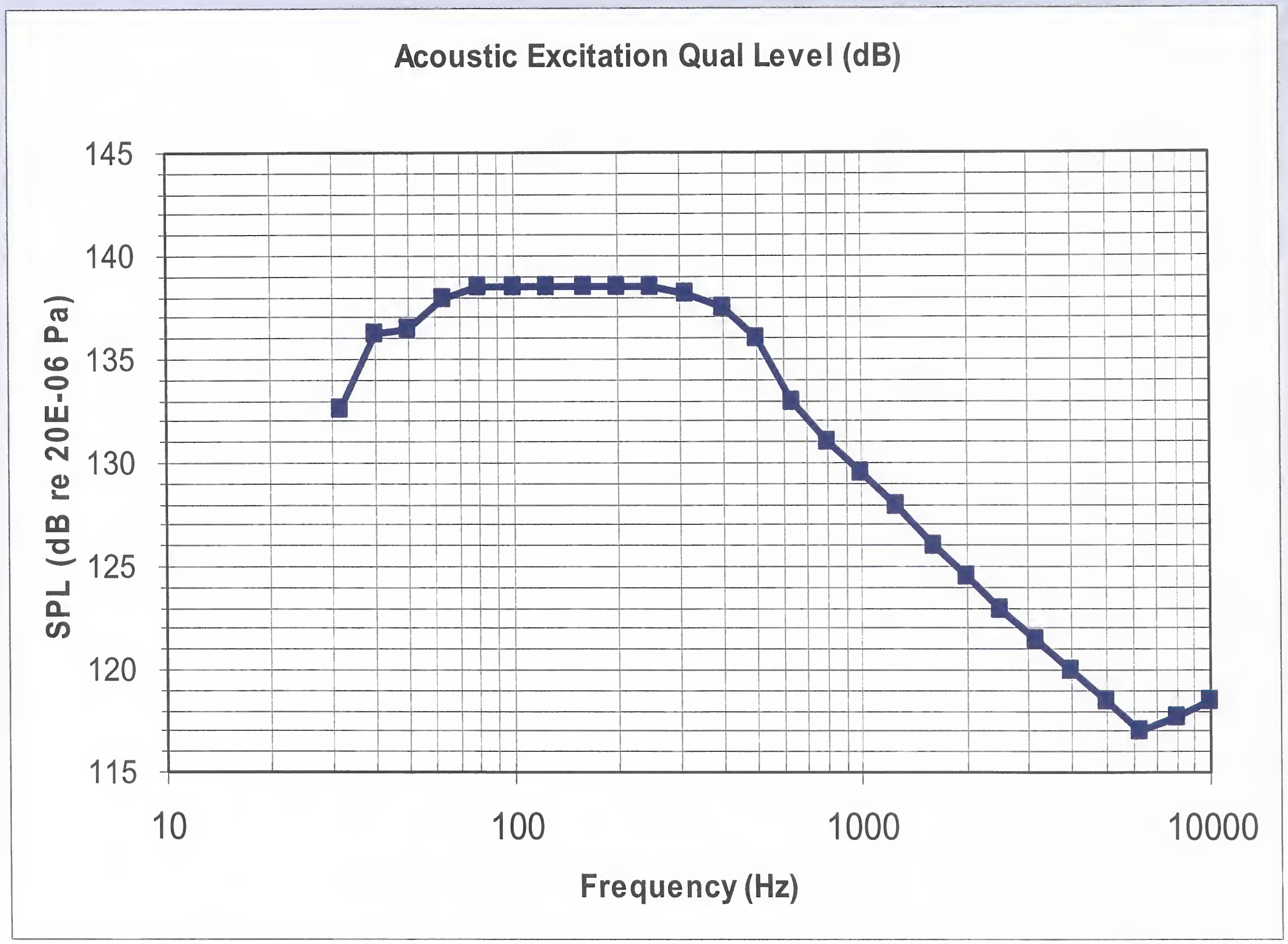
- Equivalent isotropic material properties required by AutoSEA PATH49 were calculated in VAPEPS code using EQPL. Resulting properties manually entered into AutoSEA
  - Utilized extensive GRC experience with VAPEPS and EQPL
  - Heat pipes modeled as rib stiffeners
- Current version of AutoSEA PATH49 necessitated modeling excitation using acoustic cavity
- Acoustic cavity, sized to approximate the Titan IV fairing volume, was constrained to the qualification level acoustic spectrum (149.1 dB OA)
- Plate subsystems connected to acoustic cavity using manual area junctions
  - Areas scaled by a factor of 2 to simulate two-sided excitation and radiation
- Radiation efficiencies calculated from PATH49 script
- Damping Loss Factor of 0.01 was used for conservative results
- Neither acoustic fill factor effects or stacked panel considerations were evaluated in this study
- Structure borne vibrations between individual radiator panels were considered negligible and therefore, hinges and heat pipe connections were not included

Equivalent Panel Correlations

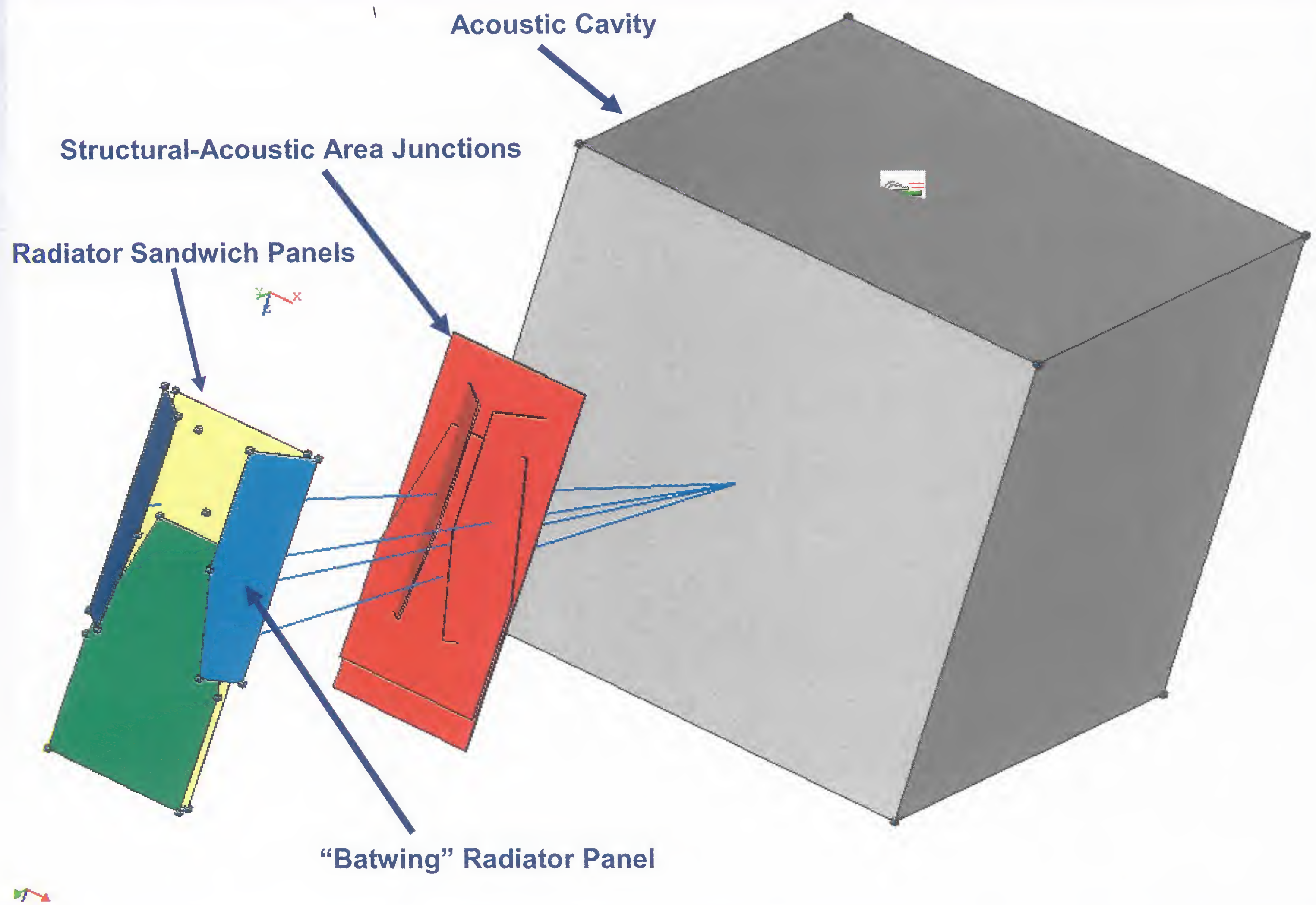
- To verify the SEA predictions, a representative panel was modeled in AutoSEA, VAPEPS and with simplified SEA theory using the VAPEPS EQPL properties
  - For the Sandwich panel radiator configuration, the “Batwing” panel was modeled
  - For the Single-Fin configuration, a single fin radiator was modeled
  - For meaningful comparisons with VAPEPS predictions, AutoSEA panel shear and extensional wavefields were turned off. Acoustic cavity surface area and perimeter were set to zero.
  - The SEA theory was implemented in an Excel spreadsheet based on Scharton, “Vibroacoustic Analysis of the THEMIS Probe”, presented at the 2004 Spacecraft and Launch Vehicle Dynamics Environments Workshop:
    - $\langle A^2\rangle_{s,t}/\langle p^2\rangle_{s,t} = [2/\rho_s^2] * [\pi\rho_s c_0/(4\kappa\rho_0 c_1)] * [2\eta_{21}/(\eta_2+2\eta_{21})]$ where,
      - $\langle A^2\rangle_{s,t}$ = space-time mean-square acceleration of panel
      - $\langle p^2\rangle_{s,t}$ = space-time mean-square acoustic pressure
      - ρ_s = mass per unit area of panel
      - C_0 = speed of sound in air
      - C_1 = longitudinal wave speed in the panel or face sheet
      - $\kappa = (\text{panel thickness})/(12)^{1/2}$
      - η_2 = damping loss factor
      - $\eta_{21} = \sigma * \rho_0 c_0/(\omega\rho_s)$ = coupling loss factor, ω=radian frequency, σ=radiation efficiency using the NASA GRC method: $\sigma=(f/f_c)^2$, $f<f_c$ and $\sigma=1$, f = or $>f_c$

Acoustic Cavity Excitation

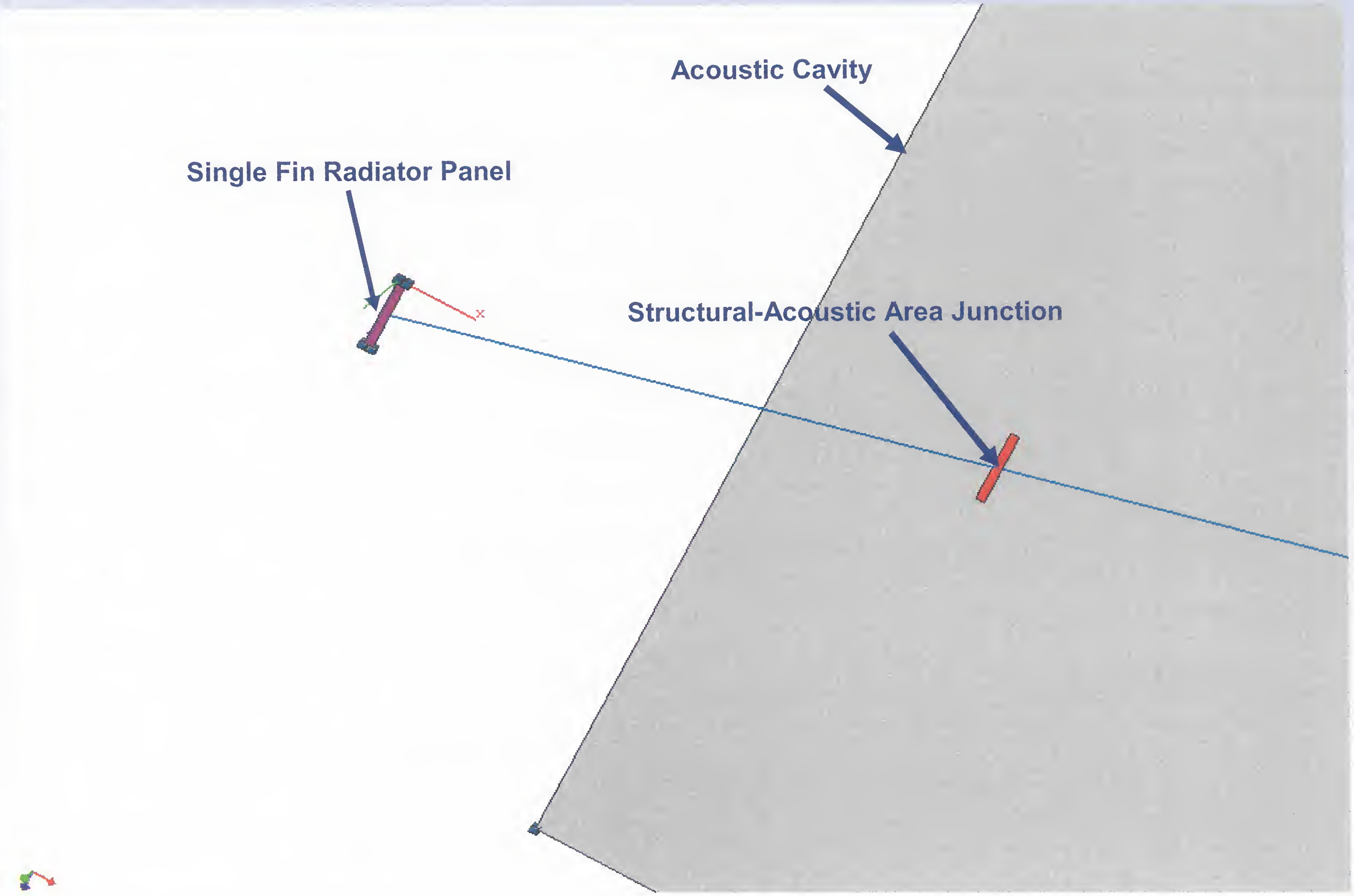
Frequency	Qual SPL
(Hz)	(dB)
31.5	132.6
40.0	136.3
50.0	136.5
63.0	138.0
80.0	138.5
100.0	138.5
125.0	138.5
160.0	138.5
200.0	138.5
250.0	138.5
315.0	138.2
400.0	137.5
500.0	136.0
630.0	133.0
800.0	131.0
1000.0	129.5
1250.0	128.0
1600.0	126.0
2000.0	124.5
2500.0	123.0
3150.0	121.5
4000.0	120.0
5000.0	118.5
6300.0	117.0
8000.0	117.7
10000.0	118.5
Overall SPL	149.1



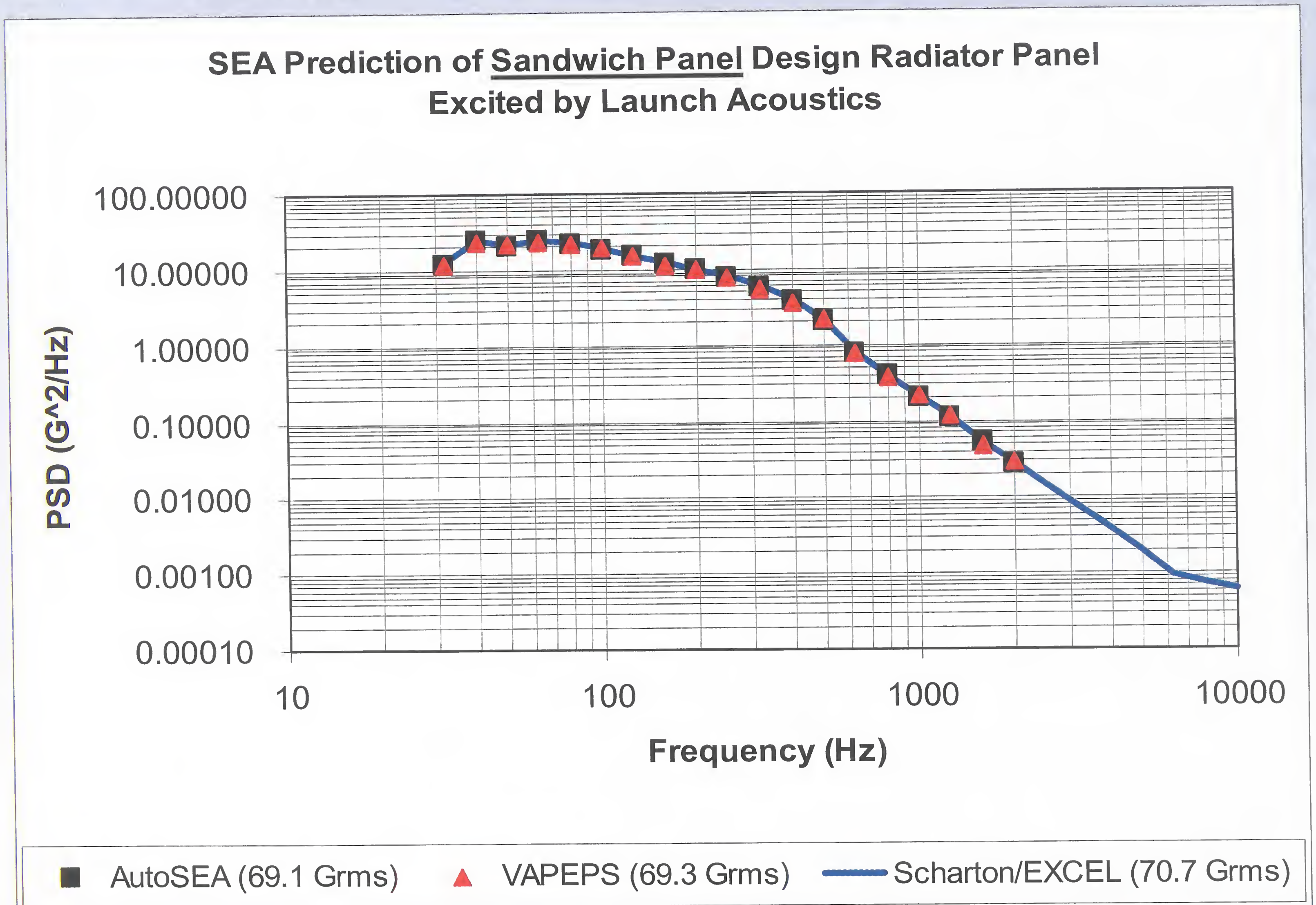
Sandwich Panel Radiator Configuration AutoSEA Model



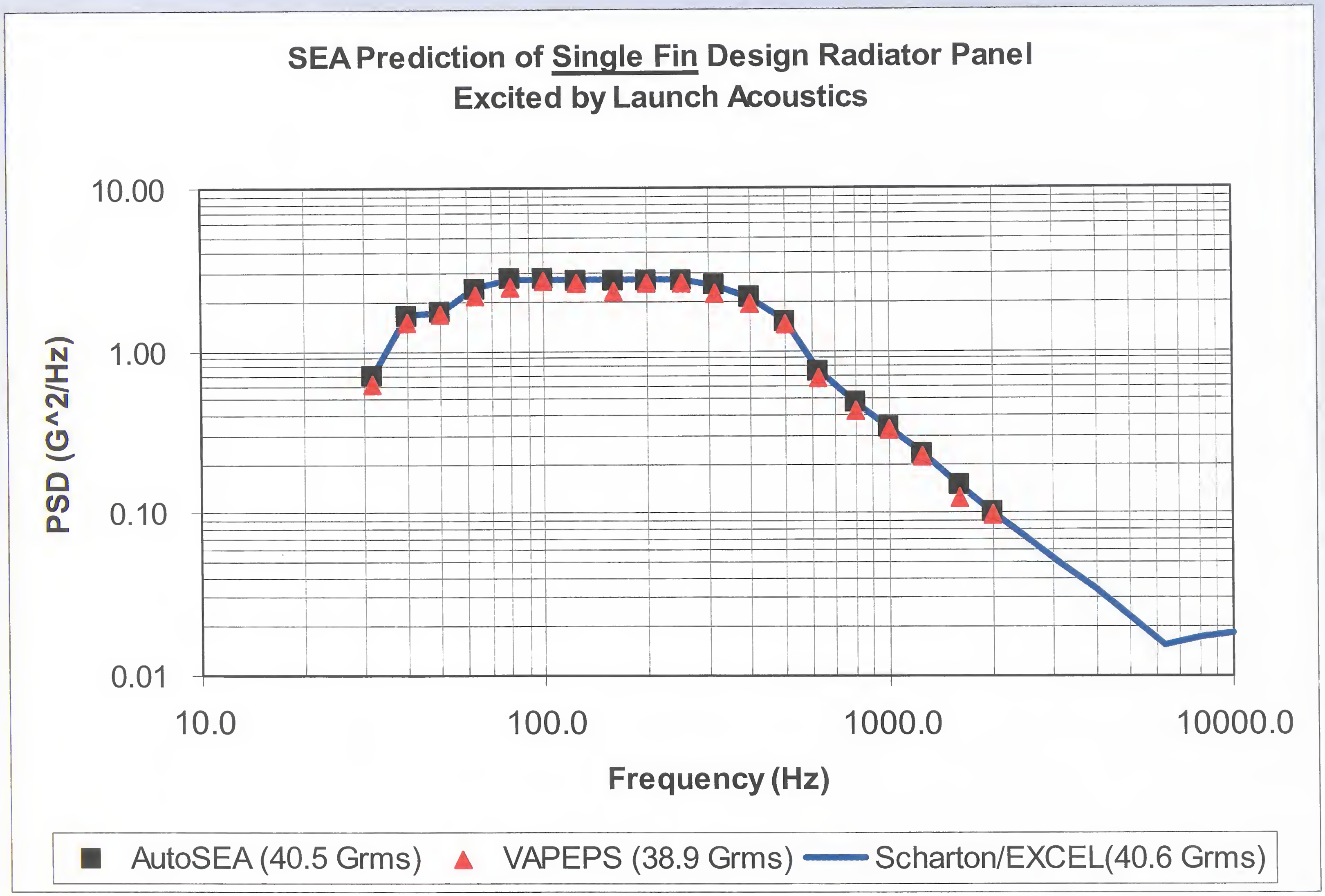
<u>Single Fin</u> Configuration AutoSEA Model



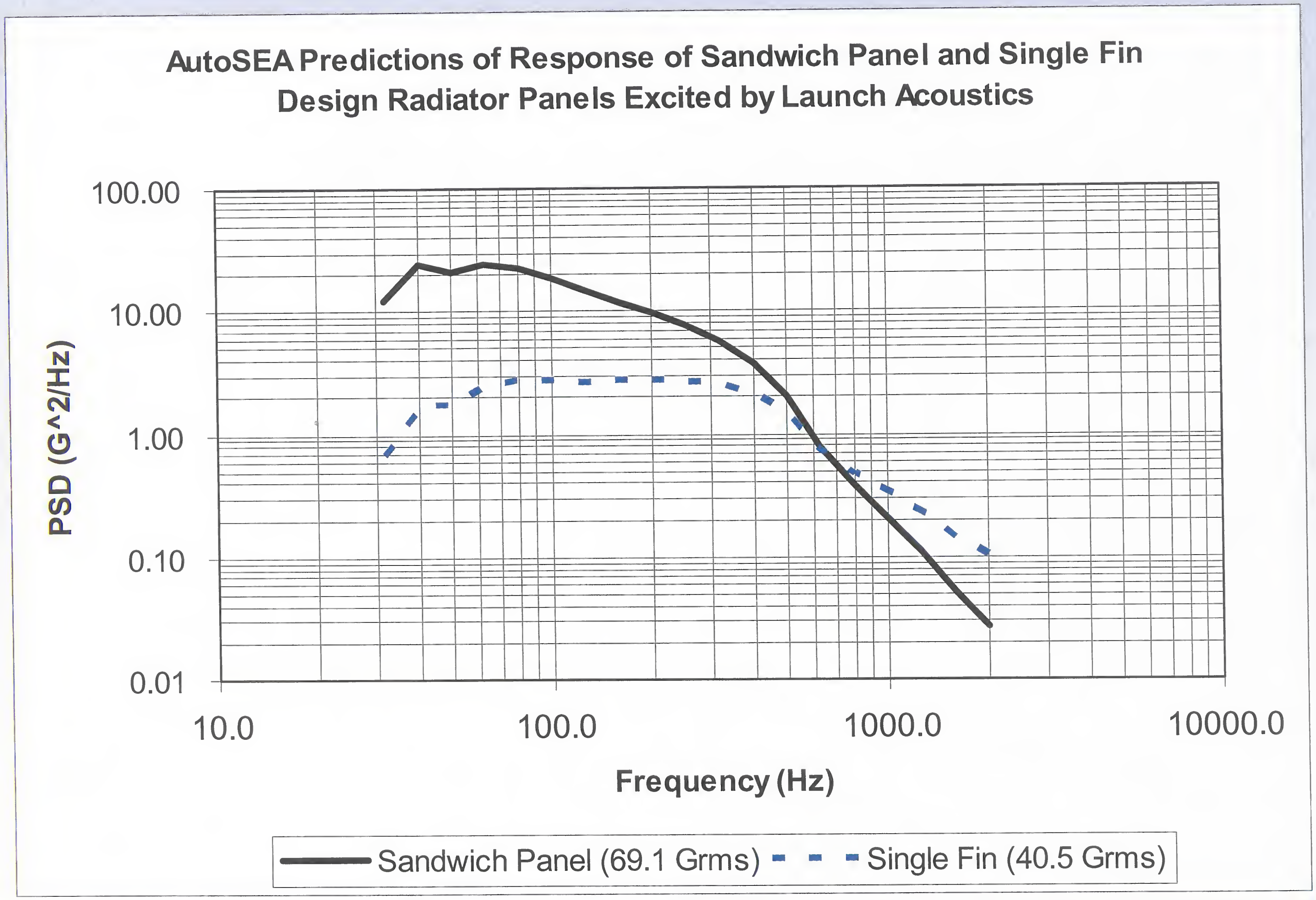
Sandwich Panel Radiator SEA Correlation



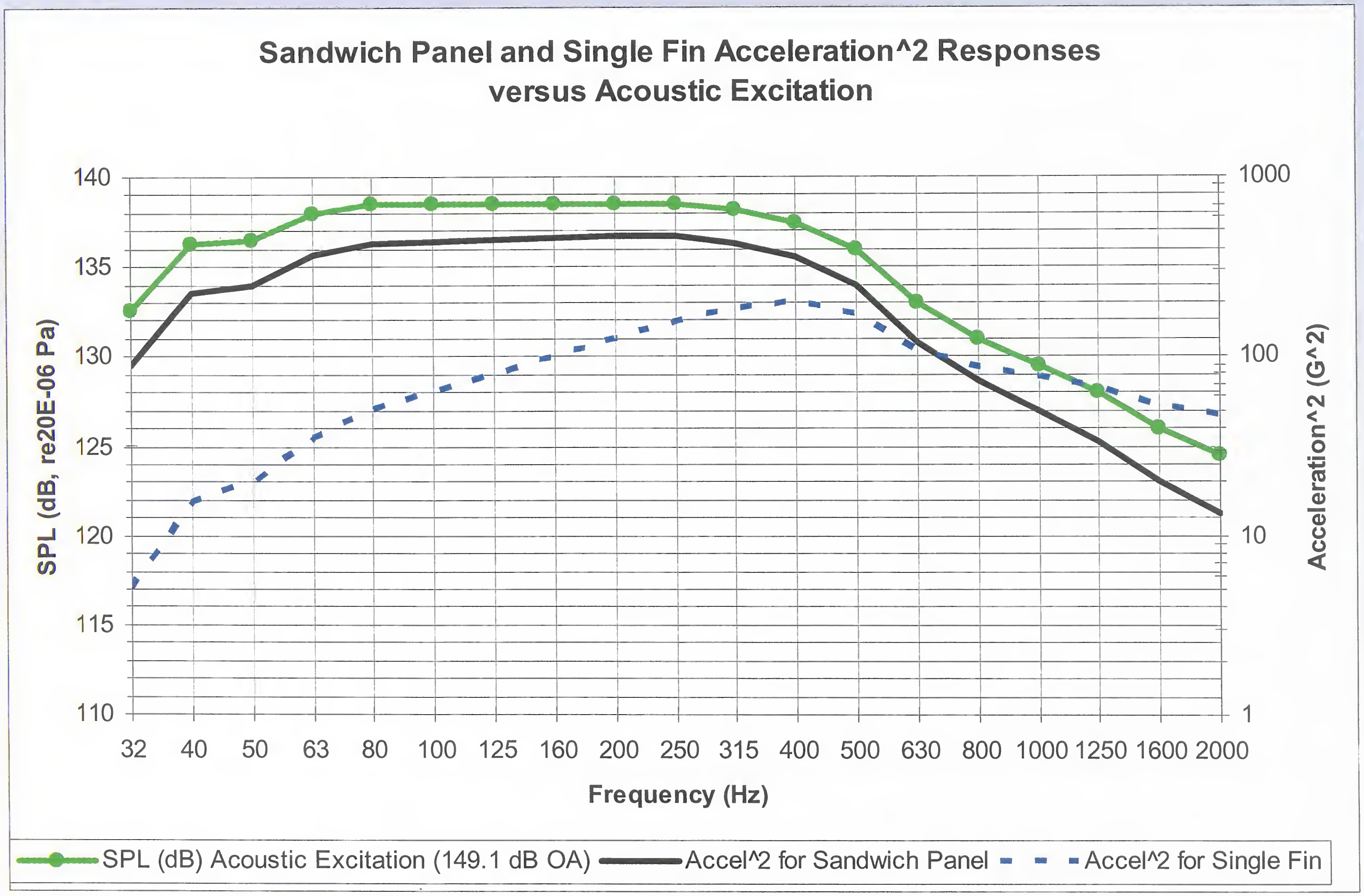
Single Fin Radiator SEA Correlation



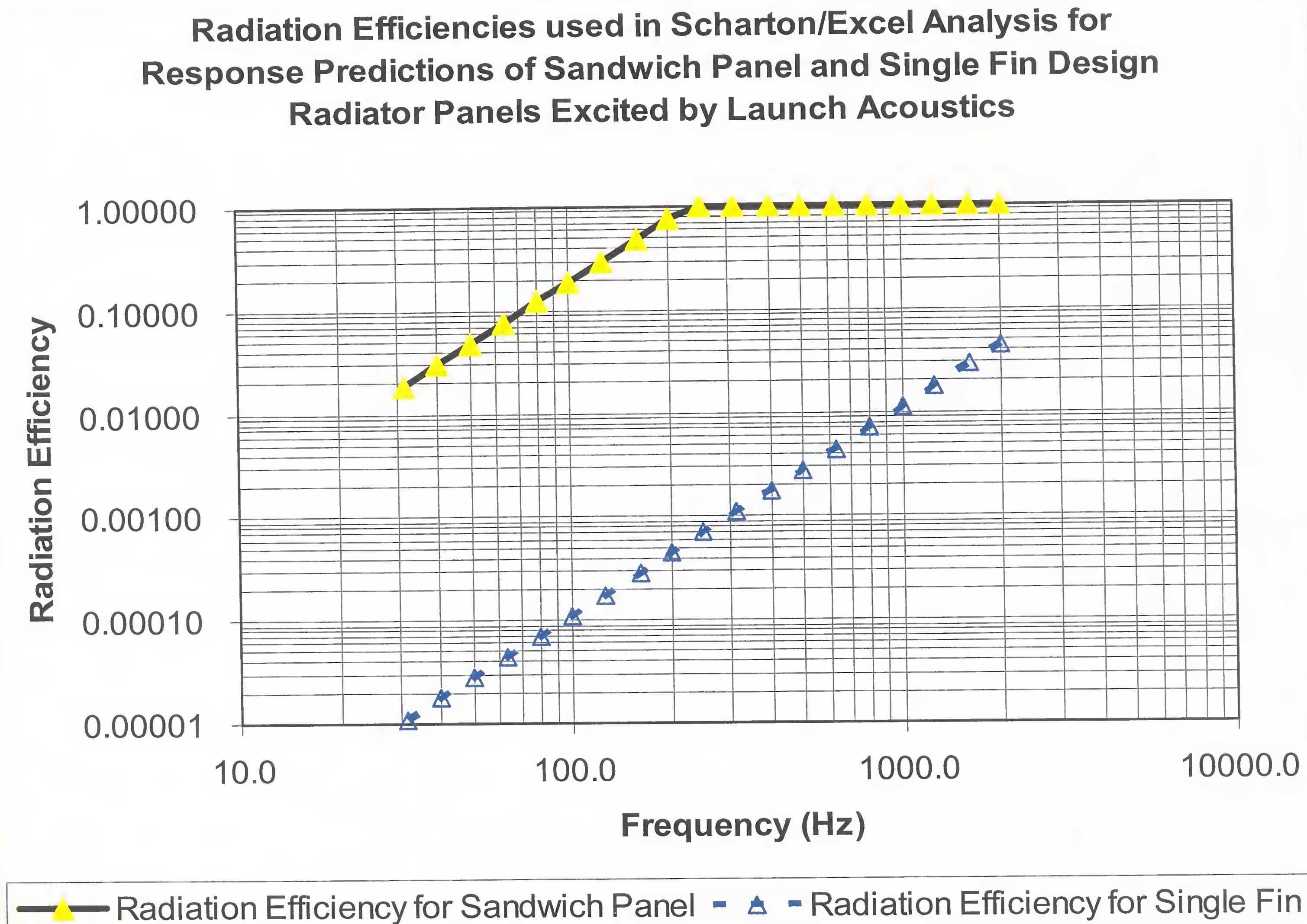
Comparison of AutoSEA Predictions



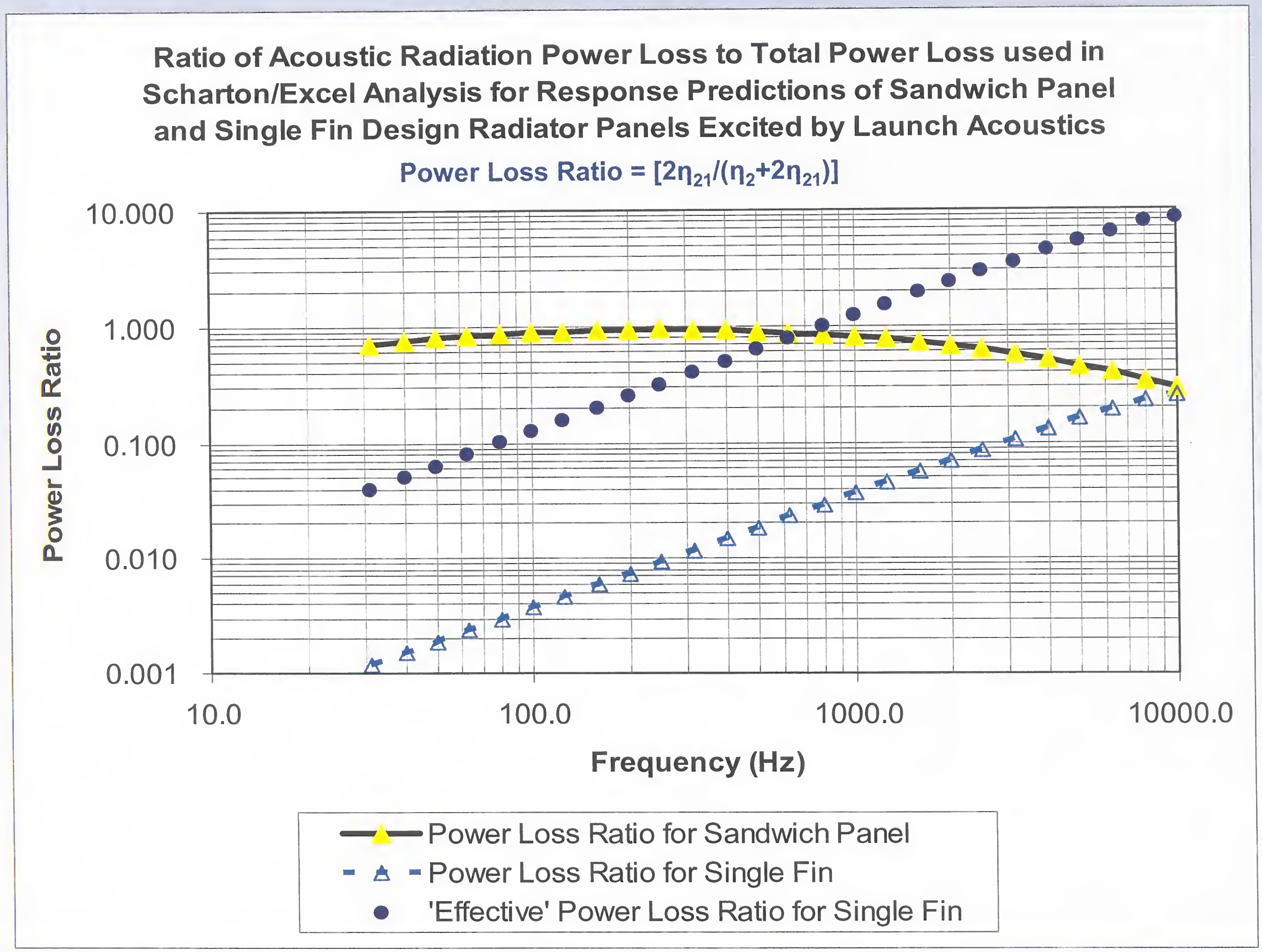
Radiator Panel Acceleration Response



Comparison of Radiation Efficiencies



Power Loss Ratios



Conclusions

- For the two spacecraft radiator panel designs considered in this launch acoustics study, the single fin panel had the lower vibration response
- Panel response is highly dependent upon radiation efficiency and the coincidence frequency.
  - Coincident frequency, f_c, sets inflection point in the radiation efficiency curve for the PATH49 formulation.
  - Equivalent panel thickness is a driving parameter in determining coincidence frequency ($f_c = c_0^2/1.8c_l t$) and therefore, the resulting radiation efficiency curve
- High f_c for the single fin panel ($f_c = 9537$ Hz) versus the sandwich panel ($f_c = 216$ Hz) results in a radiation efficiency that effectively operates like a high-pass filter.
  - This causes the single fin panel to couple poorly to the acoustic excitation in the frequency range where the launch load spectrum is highest.
- To correlate AutoSEA prediction to VAPEPS, it was necessary to turn off extensional and shear panel wavefields and set acoustic cavity area and perimeter to zero.
  - Resetting these parameters back to the AutoSEA defaults (more realistic) gives predicted results approximately 3% lower:
    - Maximum Sandwich panel radiator response: 66.8 Grms
    - Typical Single Fin radiator response: 39.3 Grms